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Meta-analyses of factors motivating climate change adaptation behaviour

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Abstract

Adaptation behaviour is of critical importance to reduce or avoid negative impacts of climate change. Many studies have examined which factors motivate individuals to adapt. However, a comprehensive overview of the key motivating factors of various adaptation behaviours is lacking. Here we conduct a series of meta-analyses using data from 106 studies (90 papers) conducted in 23 different countries to examine how 13 motivational factors relate to various adaptation behaviours. Descriptive norms, negative affect, perceived self-efficacy, and outcome efficacy of adaptive actions were most strongly associated with adaptive behaviour. In contrast, knowledge and experience, which are often assumed to be key barriers to adaptation, were relatively weakly related to adaptation. Research has disproportionately focused on studying experience and risk perception, flooding and hurricanes, and preparedness behaviours, while other motivational factors, hazards, and adaptive behaviours have been understudied. These results point to important avenues for future research.

Meta-analyses of factors motivating climate change adaptation behaviour

Climate-related hazards such as floods, heatwaves, and droughts will occur more frequently and increase in severity due to climate change¹. This will cause numerous casualties and substantial amounts of damage if no action is undertaken^{2,3}. Adaptation to climate change, defined as the process of adjustment so that negative impacts of climate change can be reduced or avoided¹, is therefore of critical importance. Protection from climate-related hazards cannot be guaranteed solely through governance or technological solutions⁴. To reduce the threats of climate change, individuals and households must engage in adaptive actions. Household-level adaptation behaviours include preparatory actions (e.g., having an emergency kit, moving furniture), purchasing insurance, seeking information about climate-related hazards or how to adapt, evacuating from climate-related hazards, and supporting climate adaptation policies.

Because of the key role that individuals and households play in successful adaptation, governments aim to identify effective ways to motivate individuals and households to adapt to climate change^{5,6}. To design such approaches, it is critical to gain insight into the factors that motivate adaptation behaviour. Interventions aimed at promoting adaptation will be most effective if they target key antecedents⁷. Many studies have been conducted to identify what factors motivate adaptive behaviour. However, a quantitative overview of the key factors that motivate adaptive behaviour across climate-related hazards is still lacking. Such an overview is important to gain an integrated and comprehensive overview of the findings from this large but disperse body of literature.

We conduct a meta-analytic investigation into the factors motivating adaptive behaviour across 106 studies from 90 papers, with a combined sample size of 64,511 participants from 23 countries. These meta-analyses extend a recent meta-analysis on the predictors of flood preparedness behaviour⁸ by including studies focussing on different types

of climate-related hazards and by investigating a wider array of both predictor and outcome variables. Specifically, we investigate the relationship between adaptation behaviour and 13 motivational factors, specifically cognitive and affective factors. These factors are included in various theoretical frameworks, including protection motivation theory^{9,10}, Person-relative-to-Event theory¹¹, the Protective Action Decision Model¹², and the Social Amplification of Risk Framework^{13,14}, which have been employed in different social science disciplines, behavioural economics, and the disaster risk reduction literature. Additionally, we examined whether selected moderators influenced the strength of the relationship between the motivational factors and adaptive behaviour. An overview of all included studies and their characteristics is provided in Supplementary Data 1. Figure 1 and Table 1 provide an overview of the data and our key findings. Below, we discuss our results based on the overall observed effect sizes in our analyses.

Motivational factors with non-significant and small effects

Governments are typically responsible for installing large-scale protective measures, such as levees, firefighter squads, and hurricane warning systems. Such measures are aimed at protecting people from climate-related hazards and may lead people to believe that it is not necessary to prepare for a hazard if they place too much trust in such measures. *Trust in specific measures implemented by the government* may therefore inhibit adaptive behaviour, which may put people at risk for climate-related hazards¹⁵. We however find no direct evidence for this reasoning, as trust in government measures was not significantly correlated with adaptation ($r = .11$, $z = 1.71$, $p = .09$, 95% CI $[-.02, .23]$). We explored whether this non-significant effect may be explained by the types of adaptive actions and government measures that have been studied. The two studies that reported the strongest positive relationships examined the relationships between trust in warning systems and subsequent evacuation. The strongest negative correlation was observed for the relationship between trust in levees and

subsequent flood-proofing. This suggests that trust in government measures can promote or hinder adaptation, depending on whether the measure facilitates adaptive behaviour (e.g., warning systems facilitate evacuation) or reduces people's perceived need for adaptation (e.g., levees may reduce the need for flood-proofing). Unfortunately, we did not have enough studies to examine this reasoning formally.

Stronger *trust in the government* was associated with more adaptive behaviour ($r = .12$, $z = 3.80$, $p < .01$, 95% CI [.06, .18]). The included studies assessed trust somewhat differently. Four studies (from the same paper) measured whether people trusted information from the government, seven studies measured whether people trusted the capabilities and intentions of the government to address climate-related hazards, and two studies measured whether people trusted the government in general. Therefore, this effect size may depend on the type of trust that is assessed. However, we did not have enough studies to formally assess this hypothesis.

Experience with natural hazards has been studied extensively in the literature (we included 44 studies) and is hypothesized to shape people's perceptions of situations and influence judgements of outcomes¹⁶. We found that experiencing a natural hazard is positively associated with adaptation ($r = .12$, $z = 5.11$, $p < .01$, 95% CI [.07, .16]). We observed a large amount of heterogeneity between studies, with effect size ranging from $r = -.29$ to $r = .65$. Therefore, we examined whether the relationship differed depending on the way experience was measured¹⁷. Some studies assessed whether participants had experienced a hazard using a simple yes-or-no measure, whereas other studies measured the intensity of an experience, such as the amount of damage sustained or the extent of physical or psychological harm to the self or close others. The latter may be a more accurate predictor of adaptive behaviour as the valence of an experience likely determines whether the experience will motivate action¹⁸. Yet, the measurement of experience was not a significant moderator ($Q(2) = 0.31$, $p = .86$),

suggesting that effect sizes were similar for intensity of an experience compared to the presence versus absence of the experience (see Table 2).

We found a small positive correlation between *place attachment*, defined as the emotional connection that people have to a place¹⁹, and adaptation behaviour ($r = .13$, $z = 3.57$, $p < .01$, 95% CI [.06, .19]). This finding supports theoretical reasoning that place attachment, reflecting strong emotional investments in a house, environment, or local community, may motivate people to undertake protective actions²⁰.

Practitioners often assume that a lack of *knowledge about climate change and climate-related hazards* is a key barrier to engaging in adaptive behaviour²¹. We found only a small positive relationship between knowledge and adaptation ($r = .14$, $z = 3.37$, $p < .01$, 95% CI [.06, .22]). Measurement of knowledge, either reflecting objective (i.e., factual) or subjective (i.e. self-assessed) knowledge, did not moderate the relationship between knowledge and adaptation ($Q(1) = 0.84$, $p = .36$), suggesting that effect sizes were similar for objective knowledge and subjective knowledge (see Table 2). Note that we removed one outlier from this moderation analysis as it influenced the significance of the effect (see Methods).

Motivational factors showing small to moderate effects

There has been much debate in the literature whether *risk perception* is an important predictor of adaptive behaviour, as both non-significant and highly significant findings have been reported²². Our results suggest that, overall, risk perception motivates adaptive behaviour ($r = .20$, $z = 9.79$, $p < .01$, 95% CI [.16, .24]). However, we found a large amount of heterogeneity in effect sizes across studies; effect sizes ranged from $r = -.18$ to $r = .60$. The relationship between risk perception and adaptation is likely stronger for intended behaviour compared to past behaviours, as undertaking adaptive actions can reduce perceived risks, weakening the relationship between these two constructs²³. Indeed, the conceptualisation of the outcome variable was a significant moderator, accounting for 18.21% of heterogeneity

between studies ($Q(2) = 14.90, p < .01$). As expected, studies that focused on the intention to engage in adaptive behaviour reported stronger positive effect sizes ($r = .29, z = 9.31, p < .01, 95\% \text{ CI } [.23, .34]$), than studies that focused on past adaptive behaviours ($r = .18, z = 6.19, p < .01, 95\% \text{ CI } [.12, .23]$).

Belief in the reality of climate change is positively associated with adaptation ($r = .23, z = 2.68, p < .01, 95\% \text{ CI } [.06, .39]$). As we could include only 5 studies for this analysis, this result should be interpreted with care. Moreover, especially the studies that assessed policy support reported positive relationships, while non-significant relationships were found for preparedness behaviours. This suggests that the strength of the relationship between climate change belief and adaptation may depend on the type of adaptive behaviour that is studied. Due to the limited number of studies, we could not investigate this hypothesis formally.

We also found a small to moderate positive relationship between *perceived responsibility* and adaptive behaviour ($r = .25, z = 4.61, p < .01, 95\% \text{ CI } [.14, .34]$). This indicates that people who perceive less personal responsibility for undertaking protective actions against climate-related hazards are less likely to engage in adaptive actions²⁴, which may put them at risk of climate-related hazards.

Finally, *injunctive norms*, reflecting perceptions of whether adaptation will be approved or disapproved by others²⁵, also shows a small to moderately strong relationship with adaptive behaviour ($r = .25, z = 6.38, p < .01, 95\% \text{ CI } [.17, .32]$). This suggests that adaptation behaviour is influenced by social motivations such as gaining social approval and avoiding social sanctions that are associated with respectively conforming versus violating an injunctive norm²⁶.

Motivational factors with the strongest relationships

Self-efficacy reflects the extent to which people believe that they are capable of engaging in relevant adaptive actions¹⁰, which may differ from an objective assessment of a

person's actual capability of adapting (i.e., adaptive capacity)²⁷. We find that perceiving higher levels of self-efficacy was associated with more adaptive behaviour ($r = .26$, $z = 3.29$, $p < .01$, 95% CI [.11, .40]). This is in line with various theories that propose that self-efficacy is one of the key determinants of (adaptive) behaviour^{10,28}.

Outcome efficacy refers to the extent to which individuals believe that adaptive actions will be effective in protecting them from climate-related hazards²⁹. We found that stronger perceived outcome efficacy is related to more adaptive behaviour ($r = .29$, $z = 7.23$, $p < .01$, 95% CI [.21, .36]). This is aligned with theoretical models that propose that perceptions of outcome efficacy are of critical importance in predicting adaptive behaviour¹⁰.

Negative affect may encourage adaptation behaviour as it is an unpleasant state of mind that people are motivated to reduce³⁰. We found that stronger negative affect was associated with more adaptive behaviour ($r = .29$, $z = 6.59$, $p < .01$, 95% CI [.21 .37]). Similar to risk perception, conceptualization of the outcome variable was a significant moderator for the relationship between negative affect and adaptation, explaining 21.03% of the heterogeneity between studies ($Q(2) = 7.47$, $p = .02$). Effect sizes were stronger for intentions to engage in adaptive behaviour ($r = .37$, $z = 7.53$, $p < .01$, 95% CI [.28, .45]) than for past adaptive behaviours, for which a non-significant relationship was found ($r = .15$, $z = 1.69$, $p = .09$, 95% CI [-.02, .31]).

Finally, *descriptive norms* refer to perceptions of whether others are engaging in adaptive actions²⁵. Descriptive norms can motivate behaviour because they signal which behaviours are likely to be effective in a situation²⁶. We find that perceived descriptive norms are positively associated adaptive behaviour ($r = .29$, $z = 4.95$, $p < .01$, 95% CI [.18, .40]). However, due to the small number of studies included in this analysis, results must be interpreted with care.

Discussion

We conducted a series of meta-analyses that examined the relationship between 13 motivational factors and adaptation. These analyses revealed that self-efficacy, negative affect, outcome efficacy, and descriptive norms were the strongest predictors of different types of adaptive behaviour. Additionally, risk perception was strongly associated with specifically people's intentions to adapt. In contrast, factors such as experience, knowledge, place attachment, and trust played only a marginal role in adaptation.

Extending previous research, we have taken a unique approach by conducting a meta-analysis across different natural hazards and adaptive behaviours. This allows us to present a comprehensive overview of the current state of the literature. Importantly, we find that the literature has disproportionally focussed on particular climate-related hazards, motivational factors, and adaptive behaviours, while neglecting others (see Figure 3 and Figure 4). This disparity in research interest causes some limitations for the current analyses and holds important implications for future research, as we will expand upon below.

We observe a large amount of heterogeneity between studies included in our analyses. This suggests that the relationships between the motivational factors that we examined and adaptation are not consistent and likely depend on moderating factors. Potentially relevant moderators in this respect may be the type of climate-related hazard and type of adaptive behaviour that are being studied. The behaviours that we examined ranged from immediate emergency responses (i.e., evacuation) to preparedness actions that protect people from climate risks in the long term (i.e., buying insurance, adaptation policy support), which may be differently related to the motivational factors. Moreover, some behaviours may be more relevant for some climate-related hazards than for others. For example, purchasing insurance may be more effective or common to protect oneself against risks of wildfires or flooding compared to hurricanes. Unfortunately, we could not systematically study the influence of

such potential moderators because most studies focused on a limited set of variables. As a result, we did not have enough studies for each ‘category’ of the moderator (four is the recommended amount)³¹ to conduct reliable moderation analyses (see Figure 3 and Figure 4). Since we were not able to account for the heterogeneity between studies, our results should be interpreted with caution, especially if only few studies were included in the analysis.

More studies are needed to disentangle such moderation effects. Specifically, future research could focus on the motivational factors, hazards, and behaviours that were particularly understudied, as indicated in Figure 3 and Figure 4. For example, heatwaves and droughts were understudied, as well as information seeking and evacuation behaviours. Interestingly, for some climate-related hazards, such as vector-borne diseases, we found no studies at all. Similarly, some adaptive behaviours (e.g., maladaptive actions) and predictive factors (e.g., psychological distance of climate change, perceived collective efficacy) could not be included in the current meta-analyses as they were not examined in the studies selected.

We further observed that there was a disproportional amount of studies examining effects of risk perception and experience on adaptation, while the effect sizes of these factors seemed to be relatively small. In fact, factors such as descriptive norms, perceived self-efficacy, and outcome efficacy seemed to play a more substantial role in explaining adaptation behaviour but were relatively understudied. Moreover, because most studies included a limited number of variables, little is known about how different motivational factors are interrelated and jointly lead to adaptation behaviour. For example, trust in implemented measures can influence adaptation behaviour indirectly via risk perception³², while knowledge may affect adaptation via risk perceptions, self-efficacy, or outcome efficacy^{10,12}.

Future studies could study combined effects of motivational factors in predicting adaptation, which would provide important insights into the relative contribution of each factor and the relationships between predictive factors. Such information on the relative contribution of factors is critical to properly interpret the effect sizes obtained in the current meta-analyses. It is key to specify relationships between factors based on sound theoretical reasoning. Our results suggest that protection motivation theory may be a relevant theory to explain adaptive behaviour¹⁰, as its key components (risk perception, outcome efficacy, and self-efficacy) were all important predictors of (intentions to engage in) adaptive behaviour in our meta-analyses. At the same time, our results suggest that the protection motivation theory could be expanded to include factors that were also important predictors of adaptation, specifically descriptive norms (see also ⁸) and negative affect. Integrating these factors into protection motivation theory may increase the accuracy with which this theory predicts adaptive behaviour.

We observe three more caveats in the literature. First, we found few experimental and longitudinal studies, which are necessary to establish the causal relationships between variables of interest. For example, one study suggests that perceived self- and outcome efficacy may be consequences, rather than predictors, of setting the intention to engage in adaptive behaviour²⁹. Second, we find few studies that test the effectiveness of interventions that aim to promote adaptation behaviour. Such studies are important to determine whether targeting key factors influencing adaptation indeed encourage adaptive behaviour, as well as to investigate why these changes occur and under which conditions particular interventions may be more or less effective (see for example ⁶). Third, we find that most studies were conducted in North America (39%), followed by Europe (35%), Asia (12%), Australia (11%), and Africa (3%). We did not find any studies conducted in Central and South America.

Particularly conducting more research in developing countries that are highly vulnerable to climate change is urgent³³.

Our results hold important practical implications. Knowledge and experience, which are often assumed to be key barriers to adaptation, were not strongly related to adaptation behaviour. Interventions aimed at promoting adaptation are likely more effective when they target antecedents that were strong predictors in the current analyses, such as self-efficacy and outcome efficacy. Providing people with information on the effectiveness and ease of specific adaptive measures may be essential to encourage people to protect themselves against climate hazards. Moreover, perceived personal responsibility was also relatively strongly related to adaptation. As governments are increasingly moving towards more inclusive risk-management and climate change adaptation strategies that place more responsibility for adaptation on individuals and households³⁴, careful communication of individuals' responsibilities in an open dialogue between authorities and individuals may be a key step to enhance the effectiveness of such more inclusive risk-management strategies.

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Methods

Inclusion criteria and selection of studies. Studies were included if they met the following criteria. First, studies had to report quantitative data on adaptation to climate-related hazards, including floods, heatwaves, vector-borne diseases, land/mudslides, drought, (tropical) storms, and wildfires³⁵. Studies that referred to adaptation to climate change in general without specifying a specific hazard were also included. Adaptation was defined as any behaviour or intention that reduces the impacts of climate-related hazards, including preparatory action (e.g., having an emergency kit, moving furniture), purchasing insurance, seeking information about climate-related hazards or how to adapt, evacuating from climate-related hazards, and supporting adaptive policies. Second, studies had to report the relationship between adaptation and a motivational factor, specifically cognitive and affective factors that could theoretically be associated with adaptation. An overview of the operational definitions of the included motivational factors used to determine whether this criterion was met is provided in Supplementary Table 1. Third, studies must express the relationship between a motivational factor and adaptation in Pearson's r , Spearman's ρ , standardized regression coefficients, Kendall's tau, or χ^2 -tests with 1 degree of freedom. If studies described relevant data but did not supply the necessary statistics, authors were personally contacted and asked to send the necessary statistics or dataset. In total, 78 authors were personally contacted, of which 13 authors responded and provided statistics or datasets for inclusion in the meta-analysis, a response rate of 17%.

Literature search. The literature search was conducted in three steps. First, the chapters on adaptation in the latest IPCC assessment report (AR5) were consulted (chapters 14-17)¹. Second, 13 reviews and meta-analyses on adaptation to specific climate-related hazards were scrutinized^{8,22,36-46}. Third, a literature search was conducted in the databases Web of Science, PsycINFO, and Scopus that combined keywords related to climate-related hazards (e.g., climate change, hurricane, flood) with keywords related to adaptation (i.e., the dependent variable) (e.g., adaptation, insurance, evacuation). The search terms used were as follows: “adapt*” “anti-malaria” “bushfire” “climate” “climate change adaptation” “cyclone” “determinants” “drought” “evacuat*” “factor” “*fire” “flood*” “hail storm” “heat wave” “heatwave” “hurricane” “insur*” “intent*” “landslide” “land slide” “malaria” “mitigat*” “mudslide” “perception*” “prepar*” “prevent*” “sea level rise” “storm” “tornado” “thunder” “tropical storm” “typhoon” “wildfire” “wild fire”. Searches in SCOPUS and Web of Science were limited to SOCI literature only. The PRISMA diagram of the search strategy is provided in Supplementary Figure 1.

Analysis strategy. Effect sizes were obtained through the following steps. First, if studies reported multiple effect sizes per sample these were combined into one summary effect size per study by averaging the effect sizes⁴⁷. For example, if a study measured three types of adaptive behaviours, this would lead to three correlations for each motivational factor. The three correlations cannot be included separately as this would violate the assumption of independent data-points that is applicable to meta-analysis. Therefore, multiple effect sizes from the same study were first summarized before being included in the meta-analysis. This approach is commonly employed by many papers that assess multiple adaptive behaviours and combine them into one adaptive behaviour index score⁴⁸. Second, if sample sizes varied across analyses due to missing data and were not specified in the correlation table, the lower bound sample size was used. Third, the signs of effect sizes from studies that used reverse-

coded items (e.g., higher score = less adaptation) were flipped when appropriate. Next, all effect sizes were first converted to Pearson's r . Spearman's rho (r_s) was converted to Pearson's r using the following formula⁴⁹:

$$r = 2 \sin\left(\frac{\pi}{6} r_s\right)$$

Standardized regression coefficients (β) were converted to Pearson's r using the following formula⁵⁰:

$$r = \beta + .05\lambda$$

In this formula, λ is a constant that takes the value of 1 when β is greater than or equal to zero, and a value of 0 when β is smaller than zero. χ^2 tests with one degree of freedom were converted to Pearson's r using the following formula⁵¹:

$$r = \sqrt{\frac{\chi^2}{n}}$$

Kendall's tau (τ) was converted to Pearson's r using the following formula⁵²:

$$r = \sin(.5\pi\tau)$$

Univariate odds-ratios were converted to Pearson's r using the following formula⁵³:

$$r = \frac{\sqrt{OR} - 1}{\sqrt{OR} + 1}$$

Lastly, the variance-stabilising transformation to Fisher's z (r_z) was performed on all correlation coefficients before the meta-analysis was conducted using the following formula⁴⁷

$$r_z = 0.5 * \ln \frac{(1 + r)}{(1 - r)}$$

Finally, coefficients were transformed back into r before reporting them using the inverse of the Fisher's z formula:

$$r = \frac{e^{2r_z} - 1}{e^{2z} + 1}$$

All analyses were conducted in R (version 3.4.3)⁵⁴ using the *metafor* package (version 2.0.0)⁵⁵. Random-effects meta-analysis models were fitted for each factor. Following Hornsey et al.⁵⁶, meta-analyses were only conducted for factors for which 5 or more studies could be found.

Normality of distributions. One of the model requirements for meta-analysis is that the effect sizes are distributed normally⁵⁷. In Supplementary Figure 2 and Supplementary Table 2 we present the histograms for each analysis and the estimates of skew and kurtosis, respectively. There were two factors for which both skew and kurtosis deviated significantly from 0, namely experience and trust in government measures. This is not surprising as these factors both had very strong outliers. Indeed, removal of the outliers solves the problems of excessive skew and kurtosis for these factors ($\text{Skew}_{\text{experience}} = -0.35$, $p = .30$, $\text{Kurtosis}_{\text{experience}} = 0.41$, $p = .52$, $\text{Skew}_{\text{trustmeasures}} = -0.45$, $p = .39$, $\text{Kurtosis}_{\text{trustmeasures}} = -0.44$, $p = .72$). Please note that visual inspection is somewhat difficult due to the small number of studies for some analyses. We conclude that there is no strong evidence that our results may have been biased because the effect sizes were not normally distributed.

Publication bias. Another problem that may bias the estimates from meta-analytic analyses is publication bias. We assessed the occurrence of publication bias using the test for funnel plot asymmetry⁵⁸, as well as failsafe N tests and the trim-and-fill procedure⁵⁹. The results indicate that none of the funnel plot asymmetry tests were significant (see Supplementary Table 3). The trim-and-fill procedure imputed data points for four analyses, namely negative affect, trust in measures, outcome efficacy, and place attachment. For three of these analyses

(negative affect, trust in measures, outcome efficacy) data was estimated to be missing at the right side of the funnel plot, meaning that only significant data points were imputed. For place attachment, one non-significant effect was imputed, which resulted in a slightly lowered but still significant overall effect size. The failsafe N tests indicated that for all factors, a substantial amount of non-significant effects would be needed to render the overall effect non-significant. In sum, there is no strong evidence that indicates that publication bias influenced the observed effect sizes in the current analyses.

Outlier analyses. Following the current best practices in meta-analysis⁶⁰, outlier analyses were conducted for each analysis to examine to what extent single studies were influencing the results. Outliers were detected in 6 of the 13 conducted analyses, namely for trust in implemented measures, experience, place attachment, knowledge, risk perception, and descriptive norms. After close inspection of the outlier analyses, we decided to remove one outlier from one analysis. We explain our treatment of outliers in more detail below.

The study by Paul et al. (2012) was flagged as an outlier in the meta-analysis examining the effects for trust in effects of implemented measures. This study reports a strong positive correlation between evacuation and trust in warning systems ($r = .67$). Other studies mostly included preparation behaviours and information seeking as their dependent variables. Moreover, two other studies focused on evacuation intentions: One of the studies reported a moderate positive relationship, while the other study did not find a significant relationship between trust in measures and adaptation. As described in the main text, the relationship between adaptation and trust in specific measures may vary depending on whether the measure facilitates adaptive behaviour (e.g., warning systems facilitate adaptation) or reduces the perceived need to adapt (e.g., levee's may reduce the need for flood-proofing). This may explain the strong positive relationship found in the study by Paul et al. (2012). This outlier

was not removed as the significance of the overall effect size does not differ with ($r = .11$, $p = .09$) or without ($r = .06$, $p = .12$) the outlier.

The studies by Cayhanto et al. (2016) and Baumann and Simms (1978) were flagged as outliers in the analysis for experience. The study by Cayhanto et al. (2016) focused on information seeking, which might explain the negative relationship ($r = -.29$) found between experience and adaptation; those with experience may already be more knowledgeable about the natural hazard. The study by Baumann and Simms (1978) reported a strong positive correlation between experience and adaptation ($r = .65$) but did not seem to differ much compared to other studies. All analyses were rerun with removal of these outliers. The outliers did not affect the overall effect size (with outliers: $r = .12$, $p < .001$, without outliers: $r = .12$, $p < .001$) nor the moderation analyses (with outliers: $Q = 0.31$, $p = .86$, without outliers: $Q = 0.74$, $p = .69$). Therefore, the outliers were not removed from the final analyses.

The study by McFarlane et al. (2010) was flagged as an outlier in the analysis for place attachment. This study focused specifically on attachment to the natural environment, while other studies focused more on attachment to communities/social environment. This may explain why this study observed a negative relationship ($r = -.087$) between place attachment and adaptation, as this study focused on wildfire preparedness behaviours that are aimed at altering the physical environment (e.g., pruning trees) to reduce the risk of wildfire. Estimates did not vary strongly with inclusion or exclusion of the outlier (with outlier: $r = .13$, $p < .001$, without outlier: $r = .15$, $p < .001$). Therefore, we chose not to remove this study from our analysis.

The study by Cahyanto et al. (2016) was flagged as an outlier in the meta-analysis examining the effects of knowledge on adaptation. This study reports a moderate negative correlation between the two constructs ($r = -.20$), while the other studies found a small positive correlation between knowledge and adaptation. However, this negative correlation

can be attributed to the fact that the outcome variable in this study was ‘information seeking’, while other studies focused on other adaptive actions such as preparatory behaviours. This study did not greatly influence the overall estimated effect size (with outlier: $r = .14$, $p < .001$, without outlier: $r = .17$). The outlier however did influence the effects of the moderation analysis. The distinction between objective and subjective knowledge was marginally significant with inclusion of the outlier ($Q(1) = 3.38$, $p = .07$, explaining 18.72% of the variance), but not if the outlier is removed ($Q(1) = 0.84$, $p = .36$, explaining 0% of the variance). Because the moderator was marginally significant because of a single study which reports a negative effect size that can be theoretically explained and which does not relate to the distinction between objective and subjective knowledge, we decided to exclude the study in reporting the moderation analysis.

The study by de Dominicis et al. (2015, study 1) was flagged as an outlier in the analysis for risk perception. While this study reports a strong positive correlation between risk perception and adaptation ($r = .60$), it does not have any apparent differences compared to other studies. The analyses were run again with removal of the outlier. This did not affect the overall effect size (with outlier: $r = .20$, $p < .01$, without outlier: $r = .20$, $p < .01$) nor the moderation analysis (with outlier ($Q(2) = 14.90$, $p < .01$; without outlier: $Q(2) = 12.95$, $p < .01$). Therefore, this study was not removed from the analysis.

One outlier was also detected in the analyses for descriptive norms (Stein et al., 2010, study 2). Due to the small number of studies in this analysis, studies are more likely to be flagged as outliers. This study did not noticeably differ from other studies. Additionally, the estimated effect size varied hardly with inclusion or exclusion of the outlier (with outlier $r = .29$, $p < .001$, without outlier $r = .25$, $p < .001$). Therefore, this study was not removed from the analysis.

Data availability

The datasets generated during and/or analyzed during the current study are available in the Open Science Framework repository⁶¹: <http://doi.org/10.17605/OSF.IO/G2JC3>

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Author contributions

A.v.V. and L.S. together developed the idea for the paper and defined the scope for the meta-analyses. A.v.V. conducted the literature search and analysed the data. A.v.V. and L.S. wrote the paper.

Competing interest

The authors declare no competing interests.

Figure legends

Figure 1. Mean meta-analytic effect sizes. The black diamonds show the meta-analytic effect size (r) for each factor. Error bars represent the 95% confidence interval around the effect size. Grey circles represent the effect size for individual studies. The size of the circle indicates study sample size. See Supplementary Figure 3 for an alternative visualization of these data.

Figure 2. Types of climate-related hazards examined. The figure shows the number of studies observed for each combination of climate-related hazard and motivational factor. Green cells indicate four or more observed studies. Yellow cells indicate one to three observed studies. Red cells indicate no observed studies.

Figure 3. Types of adaptive behaviours examined. The figure shows the number of studies observed for each combination of adaptive behaviour type and motivational factor. Green

META-ANALYSES CLIMATE ADAPTATION

cells indicate four or more observed studies. Yellow cells indicate one to three observed studies. Red cells indicate no observed studies.

Table 1

Summary of the meta-analyses for each factor

Variable	r	95% CI	k	N	I ²	Q _E	τ ²	p
Trust in implemented measures	.11	[-.02, .23]	14	9,549	96.82	258.24	.054	.09
Trust in government	.12	[.06, .18]	13	13,698	91.63	108.62	.011	.0001
Experience	.12	[.07, .16]	44	28,705	92.99	409.29	.021	< .0001
Place attachment	.13	[.06, .19]	10	3,354	75.15	36.68	.009	.0004
Knowledge	.14	[.06, .22]	13	6,560	90.96	120.98	.020	.0008
Risk perception	.20	[.16, .24]	65	38,531	93.72	1174.71	.026	< .0001
Climate change belief	.23	[.06, .39]	5	4,187	95.26	109.21	.035	.0074
Responsibility	.25	[.14, .34]	14	7,434	95.02	306.06	.037	< .0001
Injunctive norms	.25	[.17, .32]	7	2,730	74.70	22.45	.008	< .0001
Self-efficacy	.26	[.11, .40]	11	6,305	96.84	305.82	.068	.0010
Outcome efficacy	.29	[.21, .36]	20	8,516	92.70	291.24	.031	< .0001
Negative affect	.29	[.21, .37]	22	14,802	96.55	673.20	.044	< .0001
Descriptive norms	.29	[.18, .40]	5	2,093	86.94	28.49	.016	< .0001

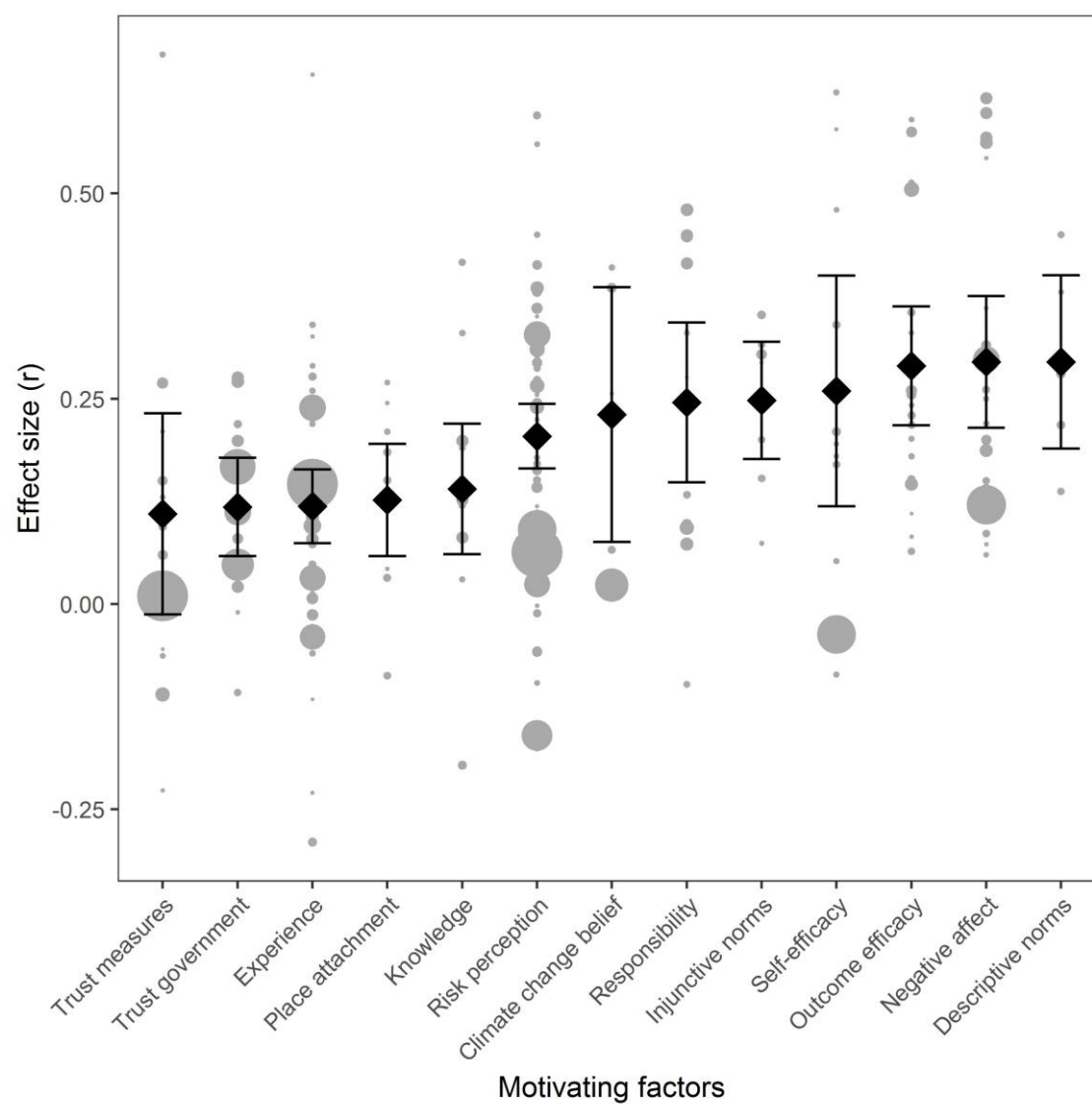
Note: r = estimated overall effect size, 95% CI = 95% confidence interval around the estimated effect size, k = number of studies included in the meta-analysis, N = number of participants across all studies included in the meta-analysis, I² = proportion of heterogeneity due to between-study differences, Q_E = total heterogeneity, τ² = absolute heterogeneity between studies, p = significance level of the estimated effect size. The total number of studies in the table (k) exceeds the 90 studies mentioned in the introduction, as most studies are included in multiple analyses.

Table 2

Moderation analyses

Variable	r	95% CI	k	p	Q _M	R ²
Experience						
<i>Moderator: Experience measure</i>			44	.8552	0.31	0.00%
Yes/No measure	.11	[.04, .18]	20	.0013		
Impact measure	.14	[.05, .22]	13	.0016		
Both	.11	[.01, .20]	11	.0253		
Knowledge*						
<i>Moderator: Knowledge type</i>			12	.3604	0.84	0.00%
Subjective knowledge	.18	[.11, .26]	9	< .0001		
Objective knowledge	.12	[-.01, .24]	3	.0801		
Risk perception						
<i>Moderator: Outcome variable</i>			65	< .0001	14.90	18.21%
Past behaviour	.18	[.12, .23]	29	< .0001		
Intended behaviour	.29	[.23, .34]	24	< .0001		
Both	.10	[.01, .18]	12	.0327		
Negative affect						
<i>Moderator: Outcome variable</i>			22	.0239	7.47	21.03%
Past behaviour	.15	[-.02, .31]	5	.0906		
Intended behaviour	.37	[.28, .45]	14	< .0001		
Both	.16	[-.05, .36]	3	.1372		

Note: * = one outlier was removed from this analysis, see Methods section for details. r = estimated overall effect size, 95% CI = 95% confidence interval around the estimated effect size, k = number of studies included in the meta-analysis, Q_M = total heterogeneity accounted for by the moderator, p = significance level of the moderator/estimated effect size, R² = variance explained by the moderator.



META-ANALYSES CLIMATE ADAPTATION

	Flooding	Hurricane	Wildfire	Heatwave	Drought	Climate change	Multiple hazards	Total
Trust in measures	8	3	3	0	0	0	0	14
Trust in government	5	0	0	1	0	6	1	13
Experience	21	14	1	1	2	1	4	44
Place attachment	3	1	5	0	0	0	1	10
Knowledge	1	2	2	2	2	4	0	13
Risk perception	27	11	9	2	4	9	3	65
Climate change belief	1	0	0	0	1	3	0	5
Responsibility	4	3	3	0	0	4	0	14
Injunctive norms	1	0	4	0	1	1	0	7
Self-efficacy	4	1	3	0	1	2	0	11
Outcome efficacy	8	1	6	2	2	1	0	20
Negative affect	9	2	2	0	1	8	0	22
Descriptive norms	1	3	0	0	1	0	0	5

META-ANALYSES CLIMATE ADAPTATION

	Preparedness	Evacuation	Insurance	Information seeking	Policy support	Multiple	Total
Trust in measures	5	3	0	0	0	6	14
Trust in government	4	0	1	0	5	3	13
Experience	16	5	7	3	0	13	44
Place attachment	7	0	0	0	0	3	10
Knowledge	6	0	0	2	4	1	13
Risk perception	27	6	5	0	3	24	65
Climate change belief	1	0	1	0	2	1	5
Responsibility	10	0	0	0	4	0	14
Injunctive norms	5	0	1	0	0	1	7
Self-efficacy	8	1	0	0	0	2	11
Outcome efficacy	13	1	1	0	0	5	20
Negative affect	7	1	0	1	6	7	22
Descriptive norms	0	3	1	0	0	1	5

